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SELF STERILITY AND CROSS STERILITY IN THE APPLE.

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BULLETIN 287

SELF STERILITY AND CROSS STERILITY IN THE APPLE.[1]

JOHN W. GOWEN.

SUMMARY

The results herein presented show that every apple grower should provide suitable varieties for pollinators if large dependable crops are to be secured.

The results presented in Tables 1 and 2 show the apple varieties which will self fertilize. No difference is noted in the fruit set when a variety is self pollinated, when it is pollinated with the pollen from different flowers on the same tree, or when it is pollinated with pollen from different trees of the same variety.

A large amount of sterility is observed in the different varieties. Out of 119 varieties only 42 set fruit, and of that 42 only 15 had a set of fruit which was even moderately commercially profitable.

Tables 3 and 4 show the results of cross pollinations within the apple. Most varieties are capable of ready cross fertilization with the pollen of other varieties. Over ¾ of those varieties pollinated with pollen of other varieties set fruit satisfactorily.

Results are presented to show that it is necessary to test a variety for cross compatibility before any conclusion can be drawn for the variety.

As pointed out the yield of orchards made up of one block of self sterile trees may be materially increased by the introduction of other varieties.

The size, color, and quality of the fruit is shown to remain practically the same as the standard for the mother parent.

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[1]Papers from the Biological Laboratory, Maine Agricultural Experiment Station, No. 133.

The number of good seeds in the crossed apples is greater than in those which are selfed.

The causes of self sterility in the apple are external and internal. The external, weather, spraying, insects, and disease, are somewhat within the control of the grower.

The chief internal cause of sterility is the slowness of growth of the pollen tube in the selfed style as against that in the crossed style.

Aside from the environmental factors, weather conditions at the blooming period, etc., there is an inborn tendency of certain plants not to produce fruit when fertilized by their own pollen or the pollen of certain varieties within their own species or different species. Among the plants with a well marked tendency in this direction of self sterility and cross sterility is the apple. The tendency of certain of the more common varieties of this species is apparently quite distinct and well marked, within other varieties the trees seem to self fertilize readily with their own pollen. It is of especial importance to the practical grower here in Maine to know what varieties are self fertile and what varieties should have other varieties near by so that the necessary crossing may take place. It is further of importance to know what varieties of those that must be crossed to produce a fair yield, should be planted together so that the best yield and quality of fruit may be obtained. A large amount of time has been devoted to the solution of this problem by the staff of the Biological Laboratory of the Maine Station.

MATERIALS AND METHODS.

The apple orchards and scattering apple trees of Highmoor Farm total to approximately 3000 trees. When the grafts are included there are about 25 different varieties represented within this group of 3000 trees. The experiments herein described include 16 of these varieties. Controlled crosses have been made between these varieties. The apples resulting from these crosses were measured. The number of good seed and the number of poor seed were determined for each cross. The germination of these seeds when planted out doors in a cold frame

was recorded in connection with the data on transplantation. These data all bear on the problem of self sterility and cross sterility in the apple and will be used in connection with this study. The publication of the results obtained from the crosses, the bearing ability of the seedling trees, and the quality of the resulting apples will form the basis of other reports on the orchard work of the Biological Laboratory.

The sterility tests are made in four ways. To test for self sterility the unopen buds are inclosed in a ten pound paper bag. These bagged flowers are treated in two ways; (a) the bags are left undisturbed until the fruit is set; (b) the bags are opened at the height of the bloom and the pollen from the anthers brushed over onto the stigmas, the bags replaced and left until the fruit is set.

The tests for cross sterility are likewise made in two ways; sterility between members of the same variety and sterility between different varieties. All of this was done with emasculated flowers, the pollen transfers being made with camel's hair brushes. In each case the flowers, both emasculated and pollinated were covered with paper bags, care being used in the removal for pollination and subsequent replacing of the paper bag to prevent accidental pollination.

When the fruit is set the paper bags used in the pollination work are replaced with cheese cloth bags. All the crosses made are tagged with a distinctive number to prevent any pedigree errors.

Self Sterility and Self Fertility.

In table 1 are shown the result of the crosses involving the pollen from a flower cluster being placed on the pistils of that same flower cluster or a different flower cluster of the same trees or different trees. The flower clusters which are only bagged depend, of course, on chance agencies to transport the pollen from the anthers to the stigmas. Those flowers which have the pollen transferred from the anthers of the flower cluster to the stigmas of the same flower cluster by means of the camel's hair brush brushing the pollen across from the one to the other eliminate this chance element. The average number of flowers worked to each flower cluster was six. The results

as given in table 1 are all for clusters which did or did not develop fruit. If it is desired to determine the fruit which set per flower the results should be multiplied by this number to obtain the number of fruit buds worked.

The selfings which matured apples are the only ones which are recorded as successful. Many of those which fall in the unsuccessful group did start to develop and some even remained after the June drop for a short time. These are not recorded, however, since this paper deals with this problem chiefly from the viewpoint of the mature, marketable fruit.

TABLE 1.

Fertility of the Ovule to Pollen Within the Same Variety.

METHOD OF POLLEN APPLICATION.

Variety	Flower cluster bagged and left		Pollinated with pollen of same tree		Pollinated with the pollen of a different tree but same variety	
	Fruit matured	No fruit	Fruit matured	No Fruit	Fruit matured	No Fruit
Baldwin	2	11	3	22		2
Ben Davis		65		229		26
Crab		3		8		
Duchess			1*	3		
Early Harvest		6		7		
Golden Russett		15		46		6
Hurlbert Sweet		5		10		
McIntosh Red		16		12		
Northern Spy		1		34	1*	3
Red Astrachan				4		
Rhode Island Greening		2		10		2
Wealthy	1					

*These apples were very poor specimens from which no seeds germinated. The seeds themselves were shrunken and shriveled.

From this table it is clear that most varieties of apples show more or less pronounced self sterility. Within the twelve varieties under consideration only four showed any fertility to their own pollen. For those which showed such fertility the Wealthy was self fertile once, the Duchess was doubtfully self fertile in one out of four trees; the Baldwin was self fertile in five out of forty crosses and the Northern Spy was doubtfully self fertile in one out of thirty-nine trials. It is clear from these results that the proportion of the flowers which are self fertile to their

own pollen is slight even with those varieties which will self fertilize. This is especially true when it is realized that each of the selfings within table 1 represent the flower cluster and not individual flowers.

The results from the different methods of pollination are chiefly negative in character. The three different groups show no material difference in the set of the fruit for the three methods. This is of interest in connection with the results of pollination with pollen of the same tree and the results of pollination with pollen of a different tree but of the same variety. The results are in each case approximately the same. This would be expected in view of the probable fact that the trees of a given variety are ultimately of the same origin, coming as they do from the same original seedling. Such results indicate the relative stability of the buds and the trees which grow from them in their presumably hereditary behavior to crossing with different kinds of pollen.

It shows further the probability that the planting of a large block of trees of the same variety, if it is self sterile, will not tend to a larger crop of fruit because for these self sterile varieties the pollen of other trees of the same variety is no more compatible than the pollen of the tree itself when applied to the stigmas.

It is of considerable interest to gather together the results on the self sterility of the apples varieties as it has been determined by the different states, both to determine on as large numbers as possible the amount of sterility which exists and also to see whether the technique or climatic conditions of one state favor the fruiting of varieties normally incompatible to their own pollen in other climates. For this purpose the results on self sterility of the different varieties have been collected and brought together in table 2.

TABLE 2.

Self Fertility and Self Sterility in the Varieties of the Apple.

Variety	Number selfed	Number fruit matured	Number fruit not matured
Arkansas Black[4]	100		100
Autumn Sweet[4]	50		50
Baldwin[1]	169	1	168

Self Fertility and Self Sterility in the Varieties of the Apple. —Continued.

Variety	Number selfed	Number fruit matured	Number fruit not matured
Baldwin	40	5	35
Baldwin[4]	200	14	186
Bailey's Sweet[4]	100	23	77
Ben Davis[4]	100	3	97
Ben Davis[13]	472	11	461
Ben Davis	320		320
Ben Davis	19		19
Bethlehemite[4]	50	10	40
Bietigheimer[4]	50		50
Bellflower (Yellow)[4]	50		50
Bottle Greening[4]	50		50
Bough, Sweet[2]	225	55	170
Canada Red[4]	50	1	49
Canada Reinette[4]	50		50
Canada Sweet[4]	50		50
Colvert[4]	100	7	93
Crab	11		11
Delaware[4]	100		100
Domine[4]	100		100
Duchess	4	1?	3
Dutch Mignonne[4]	50		50
Early Harvest	13		13
Early Harvest[2]	408	24	384
Early Ripe[2]	150		150
Early Strawberry[4]	50		50
English Russett[2]	100		100
Esopus (Spitzenburg)[1]	86	1	85
Ewalt[4]	100		100
Fallwine[4]	100	23	77
Fallawater[4]	100		100
Fall Jenneting[4]	100	3	97
Fameuse[1]	223	1	222
Fanny[2]	150		150
Gano[4]	50		50
Gilpin (Carthouse)[2]	215	7	208
Golden Russett	67		67
Golden Sweet[4]	100		100
Gravenstein[2]	95		95
Gravenstein[4]	50		50
Great Bearer[4]	100		100
Green Sweet[4]	100		100
Grimes Golden[4]	100	14	86
Grimes[13]	442	37	405
Grimes[2]	135		135
Haas[4]	100		100
Hanwell Souring[4]	50		50
Hawley	53		53
Holland Beauty[4]	50		50
Holland Pippin[4]	100		100
Hoover's Red[4]	50		50
Hurlbert Sweet	15		15
Hydes Keeper[4]	50		50
Jonathan[13]	452	17	435
Jonathan[4]	200		200
Jewett's Red[4]	50	3	47
July, Fourth of[2]	110	26	84
King	15		15
King of Tompkins Co.[4]	100		100
Keswick Codlin[4]	50	40	10
Longfellow[4]	100	27	73
Limbertwig[4]	100		100
Lily of Kent[2]	130		130
Lily of Kent[3]	116		116
Maiden's Blush[4]	100		100
Mann[4]	100	2	98
Mammoth Black Twig[4]	100		100
May[4]	100		100
McMahon White[4]	100		100

Self Fertility and Self Sterility in the Varieties of the Apple. —Continued.

Variety	Number selfed	Number fruit matured	Number fruit not matured
McIntosh Red	28		28
Melon[4]	50		50
Melon Sweet[4]	50		50
Missouri Pippin[4]	50		50
Missouri Pippin[3]	57		57
Missouri Pippin[2]	150		150
Montreal Beauty (crab)[4]	100		100
Munson Sweet[4]	50		50
Nero[2]	150		150
Newtown[4]	100	66	84
Northern Spy	38	1?	37
Northern Spy[1]	19		19
Northern Sweet[1]	113		113
Oldenburg[4]	100	5	95
Ortley[4]	100		100
Paradise Sweet[4]	100		100
Paragon[3]	195		195
Paragon[2]	180		180
Pewaukee[4]	50		50
Porter[1]	52		52
Pryor's Red[4]	50	2	48
Pumkin Russett[4]	100	16	84
Astrachan[3]	200	12	188
Ralls[4]	100		100
Rambo[4]	100	2	98
Red Astrachan	4		4
Red Astrachan[1]	16		16
Red Canada[1]	80		80
Red Cheek Pippin[4]	100		100
Red Golden Pippin[4]	50		50
Rhode Island Greening	14		14
Rhode Island Greening[4]	100		100
Rhode Island Greening[1]	703		703
Romanite[4]	100		100
Rome Beauty[4]	100		100
Roseau[1]	120		120
Roxbury (Russett)[1]	119		119
Salome[4]	100		100
Scott's Winter[4]	100	39	61
Shiawassee[4]	100	23	77
Spitzenburg[4]	100	7	93
Stark[4]	100	1	99
Stark[2]	150		150
Stayman[3]	161		161
Stayman[2]	106		106
Steel's Red[4]	50		50
Strawberry[2]	200	1	199
Red Streak[2]	200	1	199
St. Lawrence[4]	100		100
Summer Permain[4]	50		50
Summer Queen[4]	100		100
Sweet Bough[4]	50		50
Tolman (Sweet)[1]	223		223
Tolman Sweet[4]	100		100
Transcendent Crab[4]	100		100
Trumble Sweet[4]	100		100
Twenty Ounce[4]	100		100
Wealthy	1	1	
Wagener[4]	50	3	47
Washington[4]	50	7	43
Wealthy[1]	28		28
Wealthy[4]	50		50
Westfield (Seek-no-further)[1]	485		485
Western Beauty[4]	50		50
Williams (Favorite)[1]	63		63
Williams Favorite[2]	150		150
Willow Twig[4]	50	2	48
Winesap[4]	100		100

Self Fertility and Self Sterility in the Varieties of the Apple. —Concluded.

Variety	Number selfed	Number fruit matured	Number fruit not matured
Winesap[2]	300		300
Winesap[13]	550	2	548
White Pippin[4]	100	26	74
Whitney's Crab[4]	100	4	96
Yellow Transparent[2]	363	20	343
Yellow Transparent[4]	25	2	23
York Imperial[4]	100		100
York Imperial[3]	134	1?	133

Even a cursory examination of this table will show that the degree of self fertility in the apple is quite generally insignificant. Within this group of one hundred and nineteen varieties only 42 or less than half are known to have self-fertilized and set fruit. Of these 42 varieties only 15 set fruit in any numbers, the rest had only one or two fruit which matured representing something less than five per cent of the total number of crosses made.

Table 2 shows one of the best commercial varieties, the Baldwin to be self fertile in Maine and elsewhere. Of the other leading commercial varieties Rhode Island Greening, Golden Russett, Tolman Sweet, Twenty Ounce, McIntosh and Gravenstein proved to be self sterile in all tests. The varieties Northern Spy, Esopus Spitzenburg, Ben Davis, Fameuse and Oldenburg proved very slightly fertile. Of the other commercial varieties which proved somewhat more fertile might be mentioned the Jonathan, Early Harvest and Yellow Transparent.

Considerable difference is evidenced by the record of the set of fruit of a variety within the different states. The Baldwin sets a very limited number of fruit in Vermont whereas in Maine and Oregon its set of fruit was more numerous. The Ben Davis in Maine and Vermont set no fruit whereas in Arkansas and Oregon it set a limited number of apples. The Red Astrachan proved self sterile in Maine and Vermont but with a test made in Maryland set fruit on self fertilization. These results make it seem probable that the environmental conditions of the different states affect the self fertility of these differently. Caution is consequently necessary in applying the results of one state to that of another.

CROSS FERTILITY AND CROSS STERILITY IN THE APPLE.

In table 3 are shown the results of crossing one variety with the pollen of another variety. The first column records the female variety and the second column the pollen variety. In the column marked "Successful pollination" are recorded the number of pollinations which produced mature apples. In the column "Unsuccessful pollination" are recorded the number of flower clusters emasculated and pollinated.

TABLE 3.

Cross Fertility and Cross Sterility in the Apple.

Female Parent	Pollen Parent	Successful Pollination	Unsuccessful Pollination
Ben Davis	Baldwin	1*	11
Duchess	Baldwin		20
Golden Russett	Baldwin		2
Northern Spy	Baldwin	1†	12
Red Astrachan	Baldwin		4
Rhode Island Greening	Baldwin		2
Baldwin	Ben Davis		4
Golden Russett	Ben Davis	5	9
Hurlbert Sweet	Ben Davis	3	7
McIntosh Red	Ben Davis		5
Northern Spy	Ben Davis		2
Rhode Island Greening	Ben Davis		2
Ben Davis	Canada Red	5	18
Hurlbert Sweet	Canada Red	1	1
Ben Davis	Crab	9	4
Early Harvest	Crab		7
Baldwin	Duchess	1	9
Early Harvest	Duchess	1	1
Red Astrachan	Duchess	1	1
Baldwin	Golden Russett	22	5
Ben Davis	Golden Russett	5	40
Northern Spy	Golden Russett		2
Red Astrachan	Golden Russett		2
Rhode Island Greening	Golden Russett		2
Ben Davis	Gravenstein	3	22
Ben Davis	Hurlbert Sweet		11
Early Harvest	Hurlbert Sweet		2
Ben Davis	McIntosh Red	40	19
Duchess	McIntosh Red		4
Early Harvest	McIntosh Red		2
Hurlbert Sweet	McIntosh Red		4
Baldwin	Northern Spy		2
Ben Davis	Northern Spy	10	10
Golden Russett	Northern Spy	3	23
Ben Davis	Opalescent	19	23
Hurlbert Sweet	Opalescent		5
McIntosh Red	Opalescent	2	12
Baldwin	Rhode Island Greening		2
Ben Davis	Rhode Island Greening		2
Golden Russett	Rhode Island Greening		2
Northern Spy	Rhode Island Greening		2
Ben Davis	St. Lawrence	3	9
Ben Davis	Wealthy	9	3

*Not found until succeeding year when seeds were no good.
†Had six shrivelled seeds.

Forty-three different kinds of crosses were tried in testing for any cross sterility which might exist between the different varieties. Of these crosses 20 proved compatible and formed fruit. Only two of the crosses tried more than 10 times failed to set fruit. These two crosses were Duchess female x Baldwin pollen and Ben Davis female x Hurlbert Sweet pollen. When the cross was made the other way Baldwin female x Duchess pollen and Hurlbert Sweet female x Ben Davis pollen the cross was successful and fruit was matured. It is desirable, therefore, to leave those crosses which did not set fruit in abeyance until such time as more data can be collected for them before any definite conclusion is drawn on their cross sterility under Maine conditions.

Of those trees which proved fertile certain varieties stand out as quite desirable for commercial plantings. Considering the number of crosses made in conjunction with the amount of fruit set Ben Davis pollen proved quite successful with Golden Russett female; Golden Russett pollen proved to set a high percentage of the fruit when crossed with the Baldwin; Golden Russett pollen crossed fairly well with the Ben Davis; McIntosh Red pollen proved very desirable for crossing on Ben Davis female. The same was also true for the pollen of Northern Spy, Opalescent, Crab and Wealthy when crossed with Ben Davis.

Table 4 gives the same data for the varieties which have been tested for cross fertility as that given in table 2 for the self sterile varieties. The data are presented for those which are compatible and set fruit on crossing and those which did not prove compatible and did not form fruit. The crosses which are marked plus (+) or yes proved to set fruit on crossing. Those marked minus (—) did not set fruit. After those which did not set fruit is given the number of trials that were made for the given cross. From these data some estimate may be made of the probability that fruit might be set on a further crossing of these same varieties.

The percentage of fruit set or the degree of compatibility of the cross is indicated where it is known by the number of plus signs. The ± sign represents a very low percentage of fruit set with only a few number of trials. The + sign shows that a low percentage of fruit was set, the number of trials be-

ing large. The ++ sign shows a greater percentage of fruit set. The +++ sign indicates a cross which proved highly compatible by the percentage of fruit which resulted from the cross.

As these data represent the crosses which have been made in several states it gives an opportunity to compare the fruit set of the same cross under the different environmental conditions.

TABLE 4.

Cross Fertility in the Apple.

Variety	Pollen	Fruit Set	No. of Trials
Arkansas Black[14]	x Jonathan	yes	
Baldwin	x Ben Davis	—	4
Baldwin	x Duchess	+	
Baldwin	x Golden Russett	+++	
Baldwin	x Northern Spy	—	2
Baldwin	x Rhode Island Greening	—	2
Ben Davis	x Baldwin	+	
Ben Davis	x Canada Red	+	
Ben Davis	x Crab	+++	
Ben Davis[6]	x Esopus	yes	
Ben Davis	x Golden Russett	+	
Ben Davis	x Gravenstein	+	
Ben Davis[6]	x Green Newton	yes	
Ben Davis[13]	x Grimes	++	
Ben Davis	x Hurlbert Sweet	—	11
Ben Davis[13]	x Jonathan	+	
Ben Davis[6]	x Jonathan	yes	
Ben Davis[14]	x Jonathan	yes	
Ben Davis[6]	x McIntosh	yes	
Ben Davis	x McIntosh Red	+++	
Ben Davis[6]	x Mother	yes	
Ben Davis[14]	x Newtown	yes	
Ben Davis	x Northern Spy	++	
Ben Davis	x Opalescent	++	
Ben Davis	x Rhode Island Greening	—	2
Ben Davis[14]	x Rome	yes	
Ben Davis[14]	x Spitzenburg	yes	
Ben Davis	x St. Lawrence	+	
Ben Davis[14]	x Wagener	yes	
Ben Davis	x Wealthy	+++	
Ben Davis[13]	x Winesap	±	
Black Ben Davis[11]	x Hydes Keeper	yes	
Black Ben Davis[11]	x Willow Twig	yes	
Blenhein Orange[11]	x Hanwell Souring	yes	
Blenhein Orange[11]	x Arkansas Black	yes	
Blenhein Orange[11]	x Jonathan	yes	
Bloomfield[8]	x Delicious	+++	
Bloomfield[8]	x Oldenburg	+	
Bottle Greening[11]	x Pewaukee	yes	
Bottle Greening[11]	x Charlottenthaler	yes	
Delicious[8]	x Grimes	—	64
Delicious[14]	x Jonathan	yes	
Duchess	x Baldwin	—	20
Duchess	x McIntosh Red	—	4
Early Harvest	x Crab	—	7
Early Harvest	x Duchess	+	
Early Harvest[8]	x Early Ripe	±	
Early Harvest	x Hurlbert Sweet	—	2
Early Harvest	x McIntosh Red	—	2

Cross Fertility in the Apple.—Continued.

Variety	Pollen	Fruit Set	No. of Trials
Early Harvest[8]	x Red June	±	
Early Harvest[8]	x Williams	+	
Early Harvest[8]	x Yellow Transparent	±	
Early Ripe[8]	x Chenango	−	180
Early Ripe[8]	x Early Harvest	++	
Early Ripe[8]	x Kinnard	−	42
Early Ripe[8]	x Red Astrachan	+	
Early Ripe[8]	x Red June	+	
Early Ripe[7]	x Red June	++	
Early Ripe[8]	x Stayman	+	
Early Ripe[8]	x Williams	++	
Early Ripe[8]	x Yellow Transparent	++	
Early Ripe[7]	x Yellow Transparent	+	
Esopus[3]	x Ben Davis	yes	
Esopus[3]	x Jonathan	yes	
Golden Russett	x Baldwin	−	2
Golden Russett	x Ben Davis	++	
Golden Russett	x Northern Spy	+	
Golden Russett	x Rhode Island Greening	−	2
Gravenstein[8]	x Doucin	++	
Gravenstein[14]	x Jonathan	yes	
Gravenstein[14]	x Newtown	yes	
Grimes[8]	x Akin	++	
Grimes[13]	x Ben Davis	++	
Grimes[8]	x Early Ripe	±	
Grimes[13]	x Jonathan	++	
Grimes Golden[11]	x Twenty Ounce	yes	
Grimes[8]	x Stayman	+	
Grimes[13]	x Winesap	+	
Hanwell Souring[11]	x Montreal Beauty	yes	
Hanwell Souring[11]	x Charlottenthaler	yes	
Hoover's Red[11]	x Fallwine	yes	
Hoover's Red[11]	x Pewaukee	yes	
Hoover's Red[11]	x Maiden's Blush	yes	
Hurlbert Sweet	x Ben Davis	++	
Hurlbert Sweet	x Canada Red	+	
Hurlbert Sweet	x Opalescent	−	5
Hurlbert Sweet	x McIntosh Red	−	5
Hyde's Keeper[11]	x Tolman Sweet	yes	
Ingram[8]	x Rome	−	52
Ingram[3]	x Stayman	−	242
Jonathan[14]	x Arkansas Black	yes	
Jonathan[11]	x Ben Davis	yes	
Jonathan[14]	x Ben Davis	yes	
Jonathan[13]	x Ben Davis	+	
Jonathan[13]	x Grimes	+	
Jonathan[14]	x Rome	yes	
Jonathan[11]	x Spitzenburg	yes	
Jonathan[14]	x Spitzenburg	yes	
Jonathan[14]	x Wagener	yes	
Jonathan[13]	x Winesap	+	
Jonathan[14]	x Newtown	yes	
Jonathan[11]	x Yellow Newtown	yes	
Keswick Codlin[11]	x Bottle Greening	yes	
Keswick Codlin[11]	x Lady Apple	yes	
Lily of Kent[5]	x Paragon	−	53
Limbertwig[11]	x Hoover's Red	yes	
Limbertwig[11]	x Arkansas Black	yes	
Maiden's Blush[11]	x York Imperial	yes	
Mammoth Black Twig[11]	x Mann	yes	
Mammoth Black Twig[11]	x Red Astrachan	yes	
Mammoth Black Twig[11]	x Charlottenthaler	yes	
Mammoth Black Twig[11]	x Hanwell Souring	yes	
Mann[11]	x Shiawassee	yes	
Mann[11]	x Haas	yes	
Mann[11]	x Pumpkin Russett	yes	
McIntosh Red	x Ben Davis	−	5
McIntosh Red[8]	x Lawver	yes	
McIntosh Red	x Opalescent	+	
Missouri Pippin[3]	x York Imperial	+	
Mother[8]	x Bonnum	++	

Cross Fertility in the Apple.—Continued.

Variety	Pollen	Fruit Set	No. of Trials
Mother[8]	x Stayman	+	
Newtown[10]	x White Pippin	+++	
Newtown[10]	x Grimes Golden	+++	
Newtown[10]	x Jonathan	+++	
Newtown[10]	x Ben Davis	+++	
Newtown[10]	x Spitzenburg	+++	
Newtown[14]	x Spitzenburg	yes	
Newtown[14]	x Wagener	yes	
Newtown[10]	x White Bellflower	+++	
Nickajack[8]	x Stayman	—	371
Northern Spy	x Baldwin	+	
Northern Spy	x Ben Davis	—	2
Northern Spy	x Golden Russett	—	2
Northern Spy	x Rhode Island Greening	—	2
Oliver[8]	x Akin	+	
Ortley[11]	x Haas	yes	
Paragon[8]	x Bloomfield	—	60
Paragon[12]	x Lily of Kent	—	46
Paragon[5]	x Lily of Kent	+	
Paragon[12]	x Stayman	±?	
Paragon[8]	x Stayman	—	157
Paragon[5]	x Stayman	—	25
Paragon[12]	x Winesap	—	157
Pewaukee[11]	x Hoover's Red	yes	
Pewaukee[11]	x Arkansas Black	yes	
Pewaukee[11]	x Fallwine	yes	
Pewaukee[11]	x Hanwell Souring	yes	
Ralls[6]	x Northern Spy	yes	
Red Astrachan	x Baldwin	—	4
Red Astrachan	x Duchess	+	
Red Astrachan	x Golden Russett	—	2
Red June[8]	x Early Harvest	++	
Red June[8]	x Early Ripe	+	
Red June[7]	x Early Ripe	++	
Red June[8]	x Grimes	—	35
Red June[8]	x Williams	+	
Red June[8]	x Yellow Transparent	++	
Red June[7]	x Yellow Transparent	++	
Rhode Island Greening	x Baldwin	—	2
Rhode Island Greening	x Ben Davis	—	2
Rhode Island Greening	x Golden Russett	—	2
Rome[8]	x Akin	—	47
Rome[14]	x Ben Davis	yes	
Rome[14]	x Newtown	yes	
Rome[6]	x Northern Spy	yes	
Rome[14]	x Spitzenburg	yes	
Rome[8]	x Stayman	—	604
Rome[14]	x Wagener	yes	
Shiawassee[11]	x Early Strawberry	yes	
Shiawassee[11]	x Sweet Bough	yes	
Shiawassee[11]	x Tetofsky	yes	
Shiawassee B[9]	x Arkansas Black	+++	
Shiawassee C[9]	x Arkansas Black	+++	
Spitzenburg A[9]	x Baldwin	+++	
Spitzenburg[14]	x Ben Davis	yes	
Spitzenburg[14]	x Jonathan	yes	
Spitzenburg F[9]	x Jonathan	+++	
Spitzenburg[14]	x Newtown	yes	
Spitzenburg E[9]	x Newtown	+++	
Spitzenburg A[9]	x Newtown	+++	
Spitzenburg B[9]	x Ortley	+++	
Spitzenburg D[9]	x Red Cheek Pippin	+++	
Spitzenburg[14]	x Rome	yes	
Spitzenburg[14]	x Wagener	yes	
Stark[8]	x Red Astrachan	—	84
Stayman[8]	x Bonnum	+	
Stayman[8]	x Delicious	+	
Stayman[8]	x Doucin	—	40
Stayman[8]	x Early Ripe	+	
Stayman[8]	x Gravenstein	—	300
Stayman[8]	x Grimes	+	

Cross Fertility in the Apple.—Concluded.

Variety	Pollen	Fruit Set	No. of Trials
Stayman[5]	x Lily of Kent	—	20
Stayman[12]	x Lily of Kent	—	11
Stayman[3]	x Missouri Pippin	—	158
Stayman[7]	x Nickajack	+	
Stayman[8]	x Nickajack	++	
Stayman[5]	x Paragon	—	52
Stayman[3]	x Paragon	—	157
Stayman[12]	x Paragon	—	66
Stayman[8]	x Williams	++	
Stayman[12]	x Winesap	—	33
Stayman[3]	x York Imperial	+?	
Stayman[8]	x Yellow Transparent	—	10
Steele's Red[11]	x Pumpkin Russett	yes	
Steele's Red[11]	x Hoover's Red	yes	
Steele's Red[11]	x Yellow Newtown	yes	
Summer Permain[11]	x Salome	yes	
Summer Permain[11]	x Hanwell Souring	yes	
Sutton[6]	x Northern Spy	yes	
Tetofsky[11]	x Mann	yes	
Tetofsky[11]	x Haas	yes	
Wagener[14]	x Ben Davis	yes	
Wagener[14]	x Jonathan	yes	
Wagener[14]	x Rome	yes	
Wagener[14]	x Spitzenburg	yes	
Washington[11]	x Oldenburg	yes	
Washington[11]	x Hyde's Keeper	yes	
Washington[11]	x Charlottenthaler	yes	
Williams[8]	x Early Ripe	++	
Williams[8]	x Stayman	—	14
Williams[8]	x Yellow Transparent	++	
Winesap[11]	x Arkansas Black	yes	
Winesap[13]	x Ben Davis	+	
Winesap[14]	x Ben Davis	yes	
Winesap[13]	x Grimes	+	
Winesap[13]	x Jonathan	+	
Winesap[5]	x Lily of Kent	—	75
Winesap[12]	x Lily of Kent	—	29
Winesap[12]	x Paragon	—	113
Winesap[5]	x Paragon	—	102
Winesap[5]	x Stayman	+	
Winesap[12]	x Stayman	—	108
Wolf River[6]	x Yellow Transparent	++	
York Imperial[3]	x Missouri Pippin	+++	
Yellow Transparent[7]	x Early Ripe	+	
Yellow Transparent[8]	x Early Ripe	+++	
Yellow Transparent[8]	x Nickajack	+++	
Yellow Transparent[8]	x Oliver	+++	
Yellow Transparent[8]	x Red Astrachan	+++	
Yellow Transparent[8]	x Red June	+++	
Yellow Transparent[8]	x Stark	—	35
Yellow Transparent[5]	x Stayman	—	212
Yellow Transparent[8]	x Williams	+++	

Table 4 shows that of the 243 tests for cross sterility between two varieties 57 are recorded as not producing fruit, 186 as producing fruit of which 90 produced fruit but did not record the number of crosses made to accomplish its production. These figures show that over ¾ of the varieties crossed proved compatible with each other. It will be remembered that nearly ⅔ of those which were self fertilized showed no fruit production. These facts argue strongly for the necessity of arranging

for cross pollination in the commercial production of apples. If the relative set of the fruit is considered it is even more clearly demonstrated that cross pollination is necessary in commercial orcharding for of the 42 self fertilized which did set fruit as shown in table 2, less than 16 set fruit in anything but negligible amounts.

It is of some interest to examine the crosses which did not set fruit a little further to determine if possible the reason why they did not. Out of the 57 which did not prove compatible about half (26) had enough trial crosses made to make it seem likely that these crosses were nearly if not entirely, incompatible. These crosses were Delicious x Grimes, Duchess x Baldwin, Early Ripe x Chenango, Early Ripe x Kinnard, Ingram x Rome, Ingram x Stayman, Lily of Kent x Paragon, Nickajack x Stayman, Paragon x Bloomfield, Paragon x Lily of Kent, Paragon x Stayman, Paragon x Winesap, Red June x Early Ripe, Rome x Akin, Rome x Stayman, Stark x Red Astrachan, Stayman x Doucin, Stayman x Gravenstein, Stayman x Lily of Kent, Stayman x Missouri Pippin, Stayman x Paragon, Stayman x Winesap, Winesap x Lily of Kent, Winesap x Paragon, Yellow Transparent x Stark, and Yellow Transparent x Stayman. It will be noted that the varieties Stayman, Winesap and Paragon form the largest part of these sterile crosses. Stayman is known to be a seedling from the Winesap.* The Paragon is thought to have originated from the Winesap† crossed by Limbertwig. If these facts represent the true state of affairs it is entirely likely that the seedlings would also have the incompatibility of the parents from which they sprang provided, of course, that sterility in the apple is inherited in a similar manner to other known inheritance.

It is of interest to note also that the variety Lily of Kent enters into a number of these crosses. Lily of Kent x Paragon and Paragon x Lily of Kent are reciprocally sterile. Lily of Kent pollen is also sterile with Stayman and Winesap. So, likewise, is the cross between Yellow Transparent x Stayman and Stayman x Yellow Transparent reciprocally sterile. On the other hand the crosses of Nickajack x Stayman and Red June x Early Ripe are sterile but the reciprocal crosses are

*Beach, S. A., et al., 1905 The Apple of New York. vol. I, p. 318.
†Beach, S. A., et al., 1905 The Apple of New York. vol. I, p. 247.

fairly fertile and produce fruit. Crosses, Stayman x Doucin and Stayman x Gravenstein are sterile but the cross Gravenstein x Doucin is fertile. These facts make it clear that because a cross between two varieties (a x b) is sterile it is no guarantee that the reciprocal cross (b x a) will be sterile. Further if the cross of two given varieties (a x b) is sterile and the cross of two varieties including one of the given varieties (a x c) is sterile it is apparently equally possible for the two different varieties entering into the cross (b x c) to be compatible or incompatible.

The varieties which are particularly fertile when crossed are of especial interest to the man who desires to plant a commercial orchard or to increase the bearing ability of one already in existence by top working certain of the trees. Those crosses which are marked with the three pluses (+++) in table 4 should prove heavy bearers when planted together. Such orchards should be planted with the female parent, indicated in the first column, as the predominating tree in the block.

Among the leading varieties in Maine which should form desirable combinations for commercial work are Baldwin with the Golden Russett for the pollen parent; Ben Davis with McIntosh Red, Northern Spy, Opalescent or Wealthy for pollen parent; Golden Russett with Ben Davis for the pollinator. Esopus can be planted with Ben Davis and Jonathan. Newton crosses well with any of the common pollen varieties Grimes Golden, Jonathan, Ben Davis or Spitzenburg. The relative compatibility of the other varieties may be seen by consulting the lists.

The work of Alderman* makes it clear that the differences in the yield of the fruit in self and in cross pollinated orchards occupies about the same relations as are shown in the hand self pollinations of table 2 and the hand cross pollinations of table 4. In this experiment a Rome Beauty* orchard that had been bearing only moderate crops was cross pollinated by bringing in branches of other varieties and allowing the bees to work over these other varieties at the same time that they worked over the Rome Beauty. A suitable control was made with an-

*Alderman, W. H., 1917. Experimental Work on Self-sterility of the Apple. In Proc. Amer. Soc. for Hort. Sci. p. 94-101.

*The Rome Beauty as will be seen in table 2 is nearly if not quite self-sterile.

other block of Rome Beauty trees some distance away. The cross fertilized Rome Beauty trees yielded 174¼ bushels; the check Rome Beauty trees for which no arrangement for cross fertilization was made, yielded 83¼ bushels or the cross fertilized trees had nearly twice the yield of the other check block. The demonstration was made complete by a repetition of the experiment in a succeeding year.

The Growth Vigor and Resulting Size of Apples from Selfed or Crossed Varieties.

Certain objections may be made to the introduction of cross fertilization on the ground that where such cross fertilization takes place a *scrub* is produced which is worse than either parent. If such is the case it would be the height of folly to cross pollinate even though there was an increased yield, for apples are largely sold on the basis of their color, shape and size, and if these items are not properly developed the increased yield would not make up for the reduced selling price. The data in table 5 present the material to analyze this problem.

TABLE 5.

Size and Number of Seed from Selfed and Crossed Fertilized Apple Blossoms.

Varieties Crossed	No. of Individuals	Mean Diameter in Centimeters	Mean Character of Seed
Female Pollen			
Baldwin x Baldwin	5	6.36	2.8 g — 2.2 p.
Baldwin x Duchess	1	7.00	4.0 g — 3.0 p.
Baldwin x Golden Russett	48	6.36	3.8 g — 2.8 p.
Ben Davis x Canada Red	8	6.65	5.5 g — 1.4 p.
Ben Davis x Crab	12	6.25	4.4 g — 1.4 p.
Ben Davis x Golden Russett	5	5.66	6.2 g — 0.8 p.
Ben Davis x Gravenstein	3	6.53	1.7 g — 0.3 p.
Ben Davis x McIntosh Red	74	6.28	6.2 g — 1.1 p.
Ben Davis x Northern Spy	14	5.22	5.9 g — 0.4 p.
Ben Davis x Opalescent	35	6.38	7.0 g — 0.8 p.
Ben Davis x St. Lawrence	6	6.75	6.1 g — 0.2 p.
Ben Davis x Wealthy	16	4.94	4.3 g — 2.3 p.
Early Harvest x Duchess	2	----	8.0 g — 0.0 p.
Golden Russett x Ben Davis	5	6.22	7.4 g — 1.2 p.
Golden Russett x Northern Spy	3	5.40	7.7 g — 0.0 p.
Hurlbert Sweet x Ben Davis	3	7.17	4.3 g — 3.7 p.
Hurlbert Sweet x Canada Red	1	6.70	3.0 g — 3.0 p.
McIntosh Red x Opalescent	2	6.15	6.5 g — 0.5 p.
Wealthy x Wealthy	1	----	4.0 g — 0.0 p.

Data on the size and number of seeds of the apples resulting from a cross are presented in summary form from appendix table 1.

From the data contained in table 5 it is clear that the Baldwin apples resulting from cross pollination were of as good average size as were the apples which resulted from self fertilization. Since the set of fruit from the cross fertilization was larger than from the self fertilization it follows that the profit to the grower was much greater for the blossoms where cross pollination took place than where self pollination was resorted to.

The apples resulting from cross pollination of the Ben Davis were likewise all of good size from the market standpoint, as were also the apples from the other crosses. They carried more good seeds than did the self fertilized apples. From these facts we may conclude that the size of the fruit is favorably affected rather than otherwise by cross pollination.

The amount of this cross pollination affect appears to differ with different varieties. Alderman, W. H.* found that for the Rome Beauty above mentioned the cross pollination by other varieties increased the size (weight) 27.8 per cent over that of the apples resulting from self fertilization. For York Imperial the increased size for cross pollination was 42.7 per cent over the size of the selfed apple. For Wagener the effect of cross fertilization over self fertilization was in the direction of reduced size the reduction being 17.3 per cent. The results of these experiments would seem to show in general a beneficial effect of cross fertilization on size. Some work of Wicks, W. H.† using reciprocal crosses of the Ben Davis, Grimes, Jonathan and Winesap varieties to determine the effect of crossing versus selfing on the resulting color, size and quality of the fruit quite clearly shows that for these items the characters of the Mother parent varieties are found in the resulting fruit irrespective of what pollen parent is used.

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*Alderman, W. H. 1917. Experimental Work on Self-Sterility of the Apple. In Proc. Amer. Soc. for Hort. Sci. p. 94-101.

†Wicks, W. H., 1918. The Effect of Cross Pollination on Size, Color, Shape, and Quality of the Apple. In Bul. 143. Arkansas Agr. Expt. Station.

It is true that certain differences may be noted dependent upon the pollen supplied for a given cross. These differences are not in immediate relation to the variety of pollen supplied, but depend upon complex factors which will be analyzed in subsequent publications. Furthermore the effect of the crosses may be toward increased color in one cross and decreased color in another, etc. So far as the effect on the fruit is concerned it is absolutely safe and advisable to plant two varieties of different color, shape, etc. together. A red apple will be just as red if pollinated with pollen from a green variety as if pollinated with a red pollen variety. Of course the seeds resulting from such crosses will be different in the two cases, but the flesh or marketable portion will remain unchanged.

This conclusion would be expected from other independent evidence taken from histological studies of the development of the apple. The apple is like an enlarged branch of the mother tree. It does not receive anything of a genetic nature from the resulting union of the pollen and the ovule. It only acts like a sack to protect the seed. It is all maternal in origin and would therefore be expected to assume the maternal characters, size, shape, quality and color, of the mother tree.

If we look at the problem in the light of the preceding data on the self sterility and the cross sterility of the different varieties it is found that the number of fruit set from self fertilization is so limited as to make it entirely likely that the large proportion of the apples in commercial orcharding are the result of cross fertilization. Thus in table 2, one of the best commercial varieties, the Baldwin, matured on self fertilization 20 fruit out of 409 trials, a percentage of about 5. On cross fertilization this variety produced good fruit in something over 50 per cent of the crosses which were made. The Ben Davis variety matured no fruit in Maine on self fertilization yet this variety is capable of bearing a crop of a color and size consistant with the best of the variety even though the majority of fruit must have been formed by cross fertilization with a foreign pollen. In view of what the investigations on the causes of self sterility have shown in relation to the growth of the pollen tube it would seem more probable that in the commercial orchard the percentage of fruit set from self fertilization would be considerably below the percentage obtained in experimental work. Thus

given an even start the growth of the pollen tube in the style of the compatible pollen is so rapid as compared with the growth of the pollen tube of the incompatible pollen that in the majority of cases the compatible pollen would beat out the incompatible pollen in the fertilization of the ovule. Such a competitive race is, of course, eliminated in experimental work where the incompatible pollen and that only is allowed to grow in the style. Should it be assumed, however, that the number of fruit matured for the other stations is more representative of the percentages matured for the Maine Ben Davis orchards even this percentage (it is only about 1.5) will not account for the crop of fruit obtained in some of the favorable apple years, when this fruit is all of excellent size and color. These facts all strengthen the conclusions as expressed above and as demonstrated by controlled experiment in Arkansas that the color of the fruit, the size and other characteristics of the variety are as pronounced in the apple resulting from cross fertilization as they are from the apple resulting from self fertilization.

It may therefore be safely concluded that the data on cross fertilization in the apple show that an increased yield results and the size, color and quality of the apples are equal to those from self pollination. To be commercially desirable an orchard should, therefore, be a mixture of the varieties which have compatible pollen.

This conclusion may seem contrary to what is considered good commercial practice which has in the past favored large blocks of a single variety of apple. As shown above by results only recently determined, the apple tree must be crossed fertilized to produce good, regular crops of commercially desirable fruit. By this it is not meant that an orgy of promiscuous regrafting or planting of many varieties in one block is advocated. It means simply that two varieties which are reciprocally compatible should be planted together. The trees for pollination may be reduced to a minimum of only 5 per cent or one tree in 20. In planting every fourth tree in each fourth row is the pollenizer to accomplish this result. Promiscuous grafting is likewise bad commercially since it makes harvesting especially difficult. If it is desired to grow the varieties in equal proportions alternate blocks of not more than 4 or 5 rows may be

planted. In any case not more than 4 or 5 rows should separate the pollenizer trees from those to be pollinated.

For orchards already planted, regrafting a desirable pollenizer in the above mentioned proposition may be practiced. While waiting for these pollenizers to grow to bearing age a practical relief may be had by cutting large branches of other good pollinating varieties and placing them in water pails hung from the tree limbs.

Experiment has shown that little pollen fertilization is brought about by wind. Insects, wild and cultivated are the best agents to transport pollen from one variety to another. It is therefore commercially profitable to keep bees in the orchard for this purpose even though no honey is produced.

Causes of Self Sterility and Cross Sterility.

Sterility within the different species of plants appears to be due to several causal agents. These agents may be external or they may be internal. The external agents include such things as disease affecting the vitality of the tree or its blossoms such as scab, fire-blight, insect infections, spray injury before, during or after flowering. Low temperature and cold continued rains at flowering time may be other factors determining the amount of fruit set and consequently its yield. These factors are more or less under the control of the apple grower and should receive careful attention. They need not be discussed here for the remedial agents are well known.

The internal causes for sterility include degenerate pollen; pollen which is not able to cooperate properly with the style to facilitate the growth of the pollen tube at a sufficient rate of growth to reach the ovule and cause fertilization; and lack of proper development of ovule.

Within the apple the phenomena of self sterility is apparently quite universal. The crosses of the varieties which are self sterile with pollen which is crossed fertile with them show that the ovules are capable of fertilization and are therefore not responsible for the sterility resulting from the self fertilization. Similarly the argument could be made that since the pollen from a self sterile variety is capable of fertilizing other varieties the

pollen as such is not responsible in self sterile varieties of apples for the fruits not setting.

Investigation shows that the problem is one of the interrelation between the pistil and the pollen and the pollen tube. It has been shown that in the self sterile varieties self fertilized the pollen tube grows much more slowly than does the pollen tube of other varieties of pollen when used on the same pistils.* Thus in the self fertilized flower the rate of growth of the pollen tube is so slow that it cannot traverse the length of the style and fertilize the ovule before the ovule withers and dies. With the cross pollinated flowers the pollen tube grows much more rapidly and easily reaches the ovule in time for fertilization to take place. The physical basis of one form of this sterility is consequently due to some factors which inhibit the growth of the pollen tube in the style of the same variety. What this difference is, is a matter now under further investigation.

LITERATURE LIST.

1. Waugh, F. A.
1900. Report of the Horticulturist. In Thirteenth Annual Report of Vermont Agricultural Experiment Station. 1899-1900. p. 364.
2. Powell, G. Harold.
1901. Report of the Horticulturist. In Thirteenth Annual Report of the Delaware Agricultural Experiment Station, 1901, p. 114.
3. ———
1900. Report of the Horticulturist. In Twelfth Annual Report of the Delaware Agricultural Experiment Station, 1900. p. 134-139.
4. Lewis, C. I. and Vincent, C. C.
1909. Pollination of the Apple. In Bul. 104 Oregon Agricultural Experiment Station, pp. 19-20.
5. See reference 3.
6. Hedrick, W. P. and Wellington, Richard.
1912. An Experiment in Breeding Apples. In Thirty-First Annual Report of the New York Experiment Station, p. 457.
7. Ballard, W. R.
1916. Methods and Problems in Pear and Apple Breeding. In Bul. 196. Maryland Agricultural Experiment Station. p. 88.
8. See reference 7.
9. See reference 4.

*Knight, L. I., 1917. Physiological Aspects of Self-Sterility of the Apple. In Proc. Amer. Soc. Hort. Sci. p. 101-105.

10. See reference 4.
11. See reference 11.
12. Close, C. P.
1902. Report of the Horticulturist. In Fourteenth Annual Report of the Delaware Agricultural Experiment Station, p. 102.
13. Wicks, W. H.
1918. The effect of cross pollination on size, color, shape, and quality of the apple. In Bul. 143. Arkansas Agricultural Expt. Sta.
14. Vincent, C. C.
1915. Report of the Department of Horticulture. In Bul. 84, Idaho Agricultural Experiment Station, p. 24.

APPENDIX TABLE 1.

Apples Resulting from Selfing and Crossing of Varieties.

Selection Number	Parents		Diameter	No. Seeds
	Mother Parent	Pollen		
146	Baldwin	x Baldwin	5.6 cm.	2 g — 2 P
230	Baldwin	x Baldwin	5.7 cm.	6 g — 2 P
231	Baldwin	x Baldwin	6.6 cm.	— 6 P
248	Baldwin	x Baldwin	6.8 cm.	3 g —
249	Baldwin	x Baldwin	7.1 cm.	3 g — 1 P
		Average	6.36 cm.	2.8 g — 2.2 P
147	Golden Russett	x Ben Davis	6.6 cm.	10 g
148	Golden Russett	x Ben Davis	6.7 cm.	9 g
149	Golden Russett	x Ben Davis	6.6 cm.	7 g — 1 P
152	Golden Russett	x Ben Davis	5.8 cm.	8 g —
150	Golden Russett	x Ben Davis	5.4 cm.	3 g — 5 P
		Average	6.22 cm.	7.4 g — 1.2 P
16	Hurlbert Sweet	x Ben Davis	7.2 cm.	5 g — 4 P
15	Hurlbert Sweet	x Ben Davis	7.2 cm.	4 g — 4 P
18	Hurlbert Sweet	x Ben Davis	7.1 cm.	4 g — 3 P
		Average	7.17 cm.	4.3 g — 3.7 P
7	Ben Davis	x Canada Red	6.2 cm.	6 g — 1 P
8	Ben Davis	x Canada Red	5.8 cm.	4 g — 2 P
9	Ben Davis	x Canada Red	6.6 cm.	6 g — 1 P
10	Ben Davis	x Canada Red	6.5 cm.	8 g — 1 P
11	Ben Davis	x Canada Red	7.0 cm.	4 g — 4 P
12	Ben Davis	x Canada Red	7.3 cm.	6 g — 1 P
13	Ben Davis	x Canada Red	7.0 cm.	6 g —
14	Ben Davis	x Canada Red	6.8 cm.	4 g — 1 P
		Average	6.65 cm.	5.5 g — 1.4 P
3	Hurlbert Sweet	x Canada Red	6.7 cm.	3 g — 3 P
20	Ben Davis	x Crab	5.7 cm.	5 g
22	Ben Davis	x Crab	6.3 cm.	5 g — 1 P
23	Ben Davis	x Crab	6.2 cm.	4 g
26	Ben Davis	x Crab	6.7 cm.	6 g — 1 P
27	Ben Davis	x Crab	6.4 cm.	7 g — 1 P
29	Ben Davis	x Crab	6.6 cm.	6 g
30	Ben Davis	x Crab	7.3 cm.	4 g
19	Ben Davis	x Crab	6.0 cm.	3 g — 4 P
21	Ben Davis	x Crab	5.4 cm.	1 g — 4 P
24	Ben Davis	x Crab	5.9 cm.	2 g — 3 P
25	Ben Davis	x Crab	5.8 cm.	3 g — 2 P
28	Ben Davis	x Crab	6.7 cm.	7 g — 1 P
		Average	6.25 cm.	4.4 g — 1.4 P
153	Baldwin	x Duchess	7.0 cm.	4 g — 3 P
144	Early Harvest	x Duchess	?	9 g
145	Early Harvest	x Duchess	?	7 g
		Average	?	8 g
163	Baldwin	x Golden Russett	5.5 cm.	6 g
164	Baldwin	x Golden Russett	6.0 cm.	5 g
165	Baldwin	x Golden Russett	6.5 cm.	2 g — 5 P
166	Baldwin	x Golden Russett	5.5 cm.	3 g — 4 P
167	Baldwin	x Golden Russett	6.3 cm.	2 g — 7 P
168	Baldwin	x Golden Russett	6.8 cm.	2 g — 6 P
169	Baldwin	x Golden Russett	5.5 cm.	1 g — 2 P
170	Baldwin	x Golden Russett	6.1 cm.	1 g — 7 P
171	Baldwin	x Golden Russett	6.3 cm.	6 g — 3 P

Apples Resulting from Selfing and Crossing of Varieties. —Continued.

Selection Number	Parents: Mother Parent	Parents: Pollen	Diameter	No. Seeds
172	Baldwin	x Golden Russett	6.5 cm.	5 g — 1 P
173	Baldwin	x Golden Russett	5.7 cm.	5 g — 2 P
174	Baldwin	x Golden Russett	6.3 cm.	3 g — 3 P
175	Baldwin	x Golden Russett	6.2 cm.	4 g — 4 P
176	Baldwin	x Golden Russett	7.0 cm.	6 g — 3 P
177	Baldwin	x Golden Russett	6.2 cm.	5 g — 1 P
178	Baldwin	x Golden Russett	6.8 cm.	7 g —
179	Baldwin	x Golden Russett	5.8 cm.	3 g — 3 P
180	Baldwin	x Golden Russett	6.4 cm.	4 g — 3 P
181	Baldwin	x Golden Russett	5.4 cm.	3 g — 4 P
182	Baldwin	x Golden Russett	6.0 cm.	6 g — 3 P
183	Baldwin	x Golden Russett	6.2 cm.	4 g — 2 P
185	Baldwin	x Golden Russett	6.7 cm.	6 g —
186	Baldwin	x Golden Russett	7.4 cm.	8 g —
187	Baldwin	x Golden Russett	6.6 cm.	6 g — 3 P
188	Baldwin	x Golden Russett	6.7 cm.	— 4 P
190	Baldwin	x Golden Russett	6.5 cm.	3 g — 3 P
191	Baldwin	x Golden Russett	7.4 cm.	2 g — 1 P
192	Baldwin	x Golden Russett	7.7 cm.	4 g — 4 P
193	Baldwin	x Golden Russett	6.6 cm.	2 g — 1 P
194	Baldwin	x Golden Russett	6.9 cm.	1 g — 6 P
195	Baldwin	x Golden Russett	6.6 cm.	2 g — 4 P
196	Baldwin	x Golden Russett	6.5 cm.	3 g — 3 P
197	Baldwin	x Golden Russett	7.2 cm.	2 g — 5 P
198	Baldwin	x Golden Russett	6.3 cm.	2 g — 5 P
200	Baldwin	x Golden Russett	5.7 cm.	2 g — 2 P
201	Baldwin	x Golden Russett	6.5 cm.	6 g — 1 P
202	Baldwin	x Golden Russett	5.7 cm.	3 g — 5 P
203	Baldwin	x Golden Russett	6.3 cm.	5 g —
204	Baldwin	x Golden Russett	5.4 cm.	3 g — 4 P
205	Baldwin	x Golden Russett	6.2 cm.	1 g — 6 P
207	Baldwin	x Golden Russett	6.5 cm.	2 g — 3 P
208	Baldwin	x Golden Russett	6.2 cm.	2 g — 6 P
209	Baldwin	x Golden Russett	6.9 cm.	4 g — 4 P
210	Baldwin	x Golden Russett	6.5 cm.	2 g — 3 P
184	Baldwin	x Golden Russett	6.0 cm.	9 g —
189	Baldwin	x Golden Russett	6.6 cm.	8 g —
199	Baldwin	x Golden Russett	6.5 cm.	5 g —
206	Baldwin	x Golden Russett	6.3 cm.	7 g —
		Average	6.36 cm.	3.81 g — 2.8 P
227	Ben Davis	x Golden Russett	5.0 cm.	5 g — 2 P
228	Ben Davis	x Golden Russett	5.4 cm.	9 g
229	Ben Davis	x Golden Russett	5.6 cm.	4 g
242	Ben Davis	x Golden Russett	6.0 cm.	7 g
243	Ben Davis	x Golden Russett	6.3 cm.	6 g — 2 P
		Average	5.66 cm.	6.2 g — 0.8 P
4	Ben Davis	x Gravenstein	6.6 cm.	1 g — 1 P
5	Ben Davis	x Gravenstein	6.2 cm.	2 g
6	Ben Davis	x Gravenstein	6.8 cm.	2 g
		Average	6.53 cm.	1.7 g — 0.3 P
31	Ben Davis	x McIntosh	6.2 cm.	8 g
32	Ben Davis	x McIntosh	6.2 cm.	6 g — 1 P
33	Ben Davis	x McIntosh	6.0 cm.	7 g — 1 P
34	Ben Davis	x McIntosh	6.8 cm.	5 g
35	Ben Davis	x McIntosh	6.9 cm.	5 g — 1 P
36	Ben Davis	x McIntosh	6.1 cm.	3 g — 2 P
37	Ben Davis	x McIntosh	6.6 cm.	3 g — 4 P
38	Ben Davis	x McIntosh	6.2 cm.	6 g — 4 P

Apples Resulting from Selfing and Crossing of Varieties. —Continued.

Selection Number	Parents		Diameter	No. Seeds
	Mother Parent	Pollen		
39	Ben Davis	x McIntosh	6.6 cm.	5 g
40	Ben Davis	x McIntosh	5.9 cm.	7 g — 1 P
41	Ben Davis	x McIntosh	6.4 cm.	7 g
42	Ben Davis	x McIntosh	5.9 cm.	6 g — 2 P
43	Ben Davis	x McIntosh	5.8 cm.	4 g — 5 P
44	Ben Davis	x McIntosh	5.8 cm.	5 g — 4 P
45	Ben Davis	x McIntosh	6.6 cm.	7 g — 1 P
46	Ben Davis	x McIntosh	6.3 cm.	8 g —
47	Ben Davis	x McIntosh	6.5 cm.	7 g — 2 P
48	Ben Davis	x McIntosh	6.4 cm.	7 g — 2 P
49	Ben Davis	x McIntosh	6.9 cm.	7 g
50	Ben Davis	x McIntosh	6.5 cm.	5 g — 3 P
51	Ben Davis	x McIntosh	6.7 cm.	8 g — 1 P
52	Ben Davis	x McIntosh	6.8 cm.	7 g —
53	Ben Davis	x McIntosh	5.8 cm.	5 g — 3 P
54	Ben Davis	x McIntosh	6.5 cm.	8 g — 2 P
55	Ben Davis	x McIntosh	6.0 cm.	7 g —
56	Ben Davis	x McIntosh	6.6 cm.	6 g — 1 P
57	Ben Davis	x McIntosh	6.5 cm.	8 g — 2 P
58	Ben Davis	x McIntosh	6.5 cm.	7 g
59	Ben Davis	x McIntosh	6.1 cm.	4 g — 1 P
60	Ben Davis	x McIntosh	6.2 cm.	2 g — 4 P
61	Ben Davis	x McIntosh	6.5 cm.	7 g — 1 P
62	Ben Davis	x McIntosh	6.3 cm.	8 g — 1 P
63	Ben Davis	x McIntosh	6.7 cm.	9 g —
64	Ben Davis	x McIntosh	6.9 cm.	7 g — 1 P
65	Ben Davis	x McIntosh	6.6 cm.	6 g — 1 P
66	Ben Davis	x McIntosh	6.6 cm.	6 g —
67	Ben Davis	x McIntosh	6.3 cm.	7 g — 1 P
68	Ben Davis	x McIntosh	7.0 cm.	6 g — 1 P
69	Ben Davis	x McIntosh	6.1 cm.	8 g
70	Ben Davis	x McIntosh	5.8 cm.	8 g — 1 P
71	Ben Davis	x McIntosh	5.6 cm.	7 g — 1 P
72	Ben Davis	x McIntosh	4.9 cm.	1 g — 5 P
73	Ben Davis	x McIntosh	6.8 cm.	6 g —
74	Ben Davis	x McIntosh	6.3 cm.	6 g — 1 P
75	Ben Davis	x McIntosh	6.1 cm.	6 g —
76	Ben Davis	x McIntosh	5.8 cm.	8 g —
77	Ben Davis	x McIntosh	5.9 cm.	6 g — 2 P
78	Ben Davis	x McIntosh	6.1 cm.	5 g — 1 P
79	Ben Davis	x McIntosh	7.8 cm.	9 g —
80	Ben Davis	x McIntosh	6.4 cm.	4 g — 2 P
81	Ben Davis	x McIntosh	6.6 cm.	8 g —
82	Ben Davis	x McIntosh	7.0 cm.	7 g —
83	Ben Davis	x McIntosh	6.7 cm.	9 g —
84	Ben Davis	x McIntosh	6.5 cm.	7 g — 1 P
85	Ben Davis	x McIntosh	6.4 cm.	7 g — 1 P
86	Ben Davis	x McIntosh	6.4 cm.	6 g
87	Ben Davis	x McIntosh	6.8 cm.	5 g — 1 P
88	Ben Davis	x McIntosh	6.5 cm.	8 g
89	Ben Davis	x McIntosh	5.8 cm.	3 g — 3 P
90	Ben Davis	x McIntosh	5.3 cm.	8 g
91	Ben Davis	x McIntosh	5.9 cm.	8 g
92	Ben Davis	x McIntosh	6.5 cm.	5 g — 1 P
93	Ben Davis	x McIntosh	6.5 cm.	6 g — 1 P
94	Ben Davis	x McIntosh	6.3 cm.	7 g
95	Ben Davis	x McIntosh	5.6 cm.	7 g
96	Ben Davis	x McIntosh	7.0 cm.	8 g
97	Ben Davis	x McIntosh	6.4 cm.	7 g — 1 P
99	Ben Davis	x McIntosh	5.8 cm.	5 g
100	Ben Davis	x McIntosh	5.6 cm.	6 g
101	Ben Davis	x McIntosh	6.9 cm.	8 g — 1 P
102	Ben Davis	x McIntosh	5.6 cm.	4 g — 1 P
235	Ben Davis	x McIntosh	5.5 cm.	5 g
236	Ben Davis	x McIntosh	5.5 cm.	4 g — 2 P
241	Ben Davis	x McIntosh	4.5 cm.	2 g — 3 P
		Average	6.28 cm.	6.2 g — 1.1 P

Apples Resulting from Selfing and Crossing of Varieties. —Continued.

Selection Number	Parents		Diameter	No. Seeds
	Mother Parent	Pollen		
151	Ben Davis	x Northern Spy	5.4 cm.	5 g —
154	Ben Davis	x Northern Spy	5.9 cm.	6 g
156	Ben Davis	x Northern Spy	4.7 cm.	2 g
157	Ben Davis	x Northern Spy	5.0 cm.	8 g
158	Ben Davis	x Northern Spy	5.2 cm.	9 g
159	Ben Davis	x Northern Spy	5.2 cm.	9 g
244	Ben Davis	x Northern Spy	5.4 cm.	3 g — 1 P
238	Ben Davis	x Northern Spy	5.2 cm.	7 g
237	Ben Davis	x Northern Spy	5.9 cm.	9 g
234	Ben Davis	x Northern Spy	5.5 cm.	5 g — 2 P
233	Ben Davis	x Northern Spy	4.5 cm.	5 g — 3 P
247	Ben Davis	x Northern Spy	3.9 cm.	4 g
250	Ben Davis	x Northern Spy	5.2 cm.	5 g
251	Ben Davis	x Northern Spy	6.1 cm.	5 g
		Average	5.22 cm.	5.9 g — 0.4 P
160	Golden Russett	x Northern Spy	5.2 cm.	7 g
161	Golden Russett	x Northern Spy	5.6 cm.	7 g
162	Golden Russett	x Northern Spy	?	9 g
		Average	5.4 cm.	7.7 g
103	Ben Davis	x Opalescent	6.7 cm.	6 g — 3 P
104	Ben Davis	x Opalescent	6.1 cm.	3 g — 6 P
105	Ben Davis	x Opalescent	7.3 cm.	8 g — 1 P
106	Ben Davis	x Opalescent	6.1 cm.	7 g — 1 P
107	Ben Davis	x Opalescent	6.0 cm.	7 g
108	Ben Davis	x Opalescent	6.7 cm.	7 g
109	Ben Davis	x Opalescent	6.2 cm.	6 g — 1 P
110	Ben Davis	x Opalescent	5.9 cm.	6 g — 1 P
111	Ben Davis	x Opalescent	7.1 cm.	8 g
112	Ben Davis	x Opalescent	5.8 cm.	5 g — 2 P
113	Ben Davis	x Opalescent	5.6 cm.	12 g
114	Ben Davis	x Opalescent	5.1 cm.	9 g — 1 P
115	Ben Davis	x Opalescent	6.6 cm.	8 g
116	Ben Davis	x Opalescent	6.4 cm.	7 g
117	Ben Davis	x Opalescent	6.5 cm.	6 g
118	Ben Davis	x Opalescent	6.8 cm.	7 g
119	Ben Davis	x Opalescent	7.0 cm.	7 g
120	Ben Davis	x Opalescent	6.8 cm.	7 g
121	Ben Davis	x Opalescent	6.2 cm.	5 g — 3 P
122	Ben Davis	x Opalescent	5.7 cm.	5 g
123	Ben Davis	x Opalescent	6.3 cm.	7 g — 1 P
124	Ben Davis	x Opalescent	6.4 cm.	6 g
125	Ben Davis	x Opalescent	6.3 cm.	8 g
126	Ben Davis	x Opalescent	6.4 cm.	8 g
127	Ben Davis	x Opalescent	6.6 cm.	9 g — 1 P
128	Ben Davis	x Opalescent	6.2 cm.	4 g — 3 P
129	Ben Davis	x Opalescent	6.1 cm.	9 g
130	Ben Davis	x Opalescent	6.2 cm.	7 g — 1 P
131	Ben Davis	x Opalescent	6.1 cm.	8 g
132	Ben Davis	x Opalescent	7.4 cm.	7 g — 1 P
133	Ben Davis	x Opalescent	6.0 cm.	7 g
134	Ben Davis	x Opalescent	6.5 cm.	8 g — 2 P
135	Ben Davis	x Opalescent	6.3 cm.	7 g
142	Ben Davis	x Opalescent	6.6 cm.	8 g
143	Ben Davis	x Opalescent	7.4 cm.	6 g
		Average	6.48 cm.	7 g — .8 P
1	McIntosh Red	x Opalescent	6.4 cm.	7 g
2	McIntosh Red	x Opalescent	5.9 cm.	6 g — 1 P
		Average	6.15 cm.	6.5 g — 0.5 P

Apples Resulting from Selfing and Crossing of Varieties. —Concluded.

Selection Number	Parents		Diameter	No. Seeds
	Mother Parent	Pollen		
136	Ben Davis	x St. Lawrence	6.7 cm.	7 g
137	Ben Davis	x St. Lawrence	6.5 cm.	4 g
138	Ben Davis	x St. Lawrence	7.1 cm.	10 g
139	Ben Davis	x St. Lawrence	6.6 cm.	5 g
140	Ben Davis	x St. Lawrence	7.0 cm.	7 g
141	Ben Davis	x St. Lawrence	6.6 cm.	4 g — 1 P
		Average	6.75 cm.	6.1 g — 0.2 P
211	Ben Davis	x Wealthy	5.1 cm.	7 g
212	Ben Davis	x Wealthy	4.5 cm.	5 g — 1 P
213	Ben Davis	x Wealthy	4.6 cm.	3 g — 5 P
214	Ben Davis	x Wealthy	4.9 cm.	7 g
215	Ben Davis	x Wealthy	5.1 cm.	7 g
216	Ben Davis	x Wealthy	5.7 cm.	6 g
217	Ben Davis	x Wealthy	4.9 cm.	— 6 P
218	Ben Davis	x Wealthy	4.4 cm.	1 g — 5 P
219	Ben Davis	x Wealthy	5.4 cm.	g — 9 P
220	Ben Davis	x Wealthy	4.3 cm.	4 g — 2 P
221	Ben Davis	x Wealthy	5.0 cm.	— 8 P
222	Ben Davis	x Wealthy	5.0 cm.	7 g
223	Ben Davis	x Wealthy	5.0 cm.	5 g
224	Ben Davis	x Wealthy	4.1 cm.	5 g
225	Ben Davis	x Wealthy	5.1 cm.	7 g
226	Ben Davis	x Wealthy	6.0 cm.	5 g
		Average	4.94 cm.	4.3 g — 2.3 P
232	Wealthy	x Wealthy	?	4 g